U. S. NAVAL AIR DEVELOPMENT CENTER

JOHNSVILLE, PENNSYLVANIA

98500

XEROX

$1.60

U.S. NAVAL AIR DEVELOPMENT CENTER

JOHNSVILLE, PENNSYLVANIA

Aviation Medical Acceleration Laboratory

Health Physics for ANP

Bureau of Aeronautics
TED ADC AE 5207

U. S. NAVAL AIR DEVELOPMENT CENTER
JOHNSVILLE, PENNSYLVANIA

MA-5
881
4 Feb 1959

From: Commanding Officer, U. S. Naval Air Development Center
To: Chief, Bureau of Aeronautics (AE-513)

Subj: TED ADC AE-5207, Health Physics for ANP; letter report concerning

Encl: (1) Table 1 - Composition
(2) Table 2 - Activation

1. In the design of a nuclear powered aircraft, the direct radiation from the reactor must be reduced by sufficient shielding to a safe predetermined level. Such design will limit the direct radiation, but does not necessarily determine what hazards might result from the ingestion of induced activity contained as gas and particulate matter in the breathing air supply. The general nature of the ingestion problem involves a study of radioactive particles and gases which may be encountered in the operation of certain types of naval aircraft, and an evaluation of probable effects as well as methods for limiting potential hazards.

2. An initial phase of the work will undoubtedly require the gathering of available data and a careful analysis of the problem areas; namely, the nature and origin of the radioactive materials. Factors to be considered include: (1) the form and amount of expected emission of radioactive materials; (2) the relationship of such materials to the presence of particulate and gaseous matter originating from (a) sea spray, (b) dust and residue in the aircraft, (c) clouds, (d) salt nuclei and other atmospheric constituents; and (3) the subsequent dispersion of radioactive materials over adjacent sea and land areas.

3. A preliminary definition of the ingestion problem area can best be approached by calculating from assumed values what the worst situation might possibly be. For this purpose the activation is considered in three regions: (1) activation of air and dust passing through a direct air cycle reactor, (2) activation of dust and residue in the aircraft, and (3) activation of material deposited or held within the reactor for long periods of time. The problem of the diffusion of fission products through the cladding would also be expected in normal operation. The failure of a fuel element cladding might also be expected to occur with sufficient frequency as to be considered in normal operation.

4. The activation of each element in the preceding fields of inquiry may be determined. It depends upon the average neutron flux, the activation cross section for the element, the number of atoms of element irradiated, the time interval of irradiation, and the half life of the isotope formed. The following crude assumptions or estimates are made in order to facilitate calculations:

(1) The air flow through the reactor is considered equivalent to four T-57 engines, or 650 lb/sec. A density of 13 cu. ft/lb results in 8450 cu. ft/sec.

(2) The effective reactor temperature is about 1600 degrees F.

(3) A neutron flux in the reactor core of 10^{14}/cm^2-sec is considered to be thermal.

(4) The effective length of the reactor is considered 36 inches.

(5) The velocity of air in the reactor core is about 200 ft/sec (.015 sec = time in the reactor).

(6) The amount of sea water to pass through the reactor is less than .21 lb/sec (as rain)

(7) The concentration of salt in sea air is less than 1,000 lb/mile^3.

(8) The concentration of dust in air is less than .5 mg/meter^3.

(9) The number of salt particles in air is less than 10^4/in^3.

(10) The total radiation level in the fuselage region is 100 mrem/hr. The neutron level is 50 mrem/hr (slow). 480 n/cm^2-sec = one mrem.

(11) The effective fuselage volume is 60,000 cu. ft.

5. To determine the activation of air passing through the reactor, air is considered to have the following composition:

Element	Mole Fraction %
Nitrogen (N_2)	78.09
Oxygen (O_2)	20.95
Argon (A)	0.93
Carbon Dioxide (CO_2)	0.03
Neon (Ne)	1.8×10^{-3}
Helium (He)	5.24×10^{-4}
Krypton (Kr)	1.0×10^{-4}
Hydrogen (H_2)	5.0×10^{-5}
Xenon (Xe)	8.0×10^{-6}
Ozone (O_3)	1.0×10^{-6}
Radon (Rn)	6.0×10^{-18}

6. Ninety-eight and three-tenths per cent of the upper portion of the earth's crust to a depth of a few miles is composed of eight elements; eighty-odd other elements make up 1.7% of the crust. For the purpose of this analysis, dust will be considered to be composed of the eight major elements in the following ratio:

Oxygen	47% by weight
Silicon	27%
Aluminum	8%
Iron	5%
Calcium	2.28%
Magnesium	2.28%
Potassium	2.28%
Sodium	2.28%

7. It is expected that ordinary household dust or perhaps dust found in a seaplane would contain considerable quantities of organic matter. Since information upon which to base estimates of the amount of organic matter is not readily available, such material has not been included.

8. Sea water contains about 32 elements, of which oxygen, chlorine, bromine, sulphur, potassium, sodium, calcium, and magnesium are the most important. Copper, lead, zinc, nickel. cobalt, and manganese occur at appreciable concentration only in sea weeds and corals. For the purpose of this calculation, sea water is considered to contain the following percentage by weight:

NaCl	2.7213
$MgCl_2$	0.3807
$MgSO_4$	0.1658
$CaSO_4$	0.1260
K_2SO_4	0.0863
$CaCO_3$	0.0123
$MgBr_2$	0.0076
Silver and gold	4×10^{-6} grains/kg

9. Results and Conclusions:

a. The activity may be estimated for the fuselage area where a flux of 50 X 480 n/cm^2-sec. is assumed to exist.* Saturation activity is assumed to exist, in which case the build-up of activity is equal to the rate of decay or the number of atoms multiplied by the cross section. With the assumed conditions for dust and salt nuclei, a total disintegration rate of about 10-100 per sec. could be expected, which corresponds to about 8×10^{-8} microcuries/cm^3. This value is within acceptable limits for most radioactive gases and dusts; however, it can be trusted as only a gross estimate of the activation of the dust and salt in the fuselage area.

b. We may conclude from the data in Table I and Table II that a dilution of the effluent gas from the reactor by a factor of 10^3 (argon being the deciding factor) would be required to reach maximum permissible concentration as established by the National Bureau of Standards Handbook 61. The argon-41 has a half life of 109 minutes, and approximately a ten-hour period would be required for decay to maximum permissible levels.

* Table I shows the relative cross sections and composition for the various nuclide. Table II gives the calculated activities.

c. Experience gained from this initial consideration indicates three main potential hazards that require investigation. These are as follows:

(1) The release of fission products by both diffusion through the fuel element cladding and rupture of the cladding.

(2) Activation of particulate matter remaining in the reactor for periods greater than the normal time taken for air to pass through the reactor. The situation would be analagous to the sloughing off of boiler scale in a steam system.

(3) The nature of the dusts encountered, the organic components, and how much of a hazard they create.

d. These problems require a knowledge of the kinetics of lung retention and elimination to establish hazards. Insufficient data are available to permit satisfactory elucidation of the kinetics of lung retention and elimination for a single radionuclide under any specific set of conditions. Some data are available for plutonium and fission products. This problem appears almost hopelessly complex. Lung retention and elimination have been shown to depend upon particle size, solubility, hygroscopicity, wetting, concentration, respiration rate, particle density, flocculation, and upon the chemical nature of the material inhaled.

10. This report was prepared by John D. Taylor of the Health Physics Branch and approved by Dr. James D. Hardy, Research Director of the Aviation Medical Acceleration Laboratory.

F. K. Smith

F. K. SMITH
By direction

Copy to:
Addressee (12)
Chief, BuMed
NAMC (ACEL)

COMPOSITION

ENCLOSURE (1)

Element	Air (MW 28.577)		Salt Water		Dust 1.13g/sec (.015) (sec.)		Isotope Ratio
mf = mole fraction % for air	4.43 kg/sec = 155gm mole/sec.		No. gm in reactor	No. of moles in reactor	$1.695 X 10^{-2}$ gm in reactor		Isotope - % - half life - cross section
	MW	gm moles through reactor in .015 sec.			% by weight	No. of moles in reactor	
Nitrogen (N_2)	28.016	121.03					N14 99.36% No activation N15 0.37% 7.4 sec. 24 ± 8 m barns
Oxygen (O_2)	32.00	32.47	H_2O 1.38 gm all other	7.67 X 10^{-2} 1.63X 10^{-4}	47%	4.98 X10-3	O^{16} 99 5 9% No activation O^{17} .037% 5,570 yr C^{14} 0.5 ± 0.1 barn O^{18} .204% 29 sec .21 ± .04 m barn
Argon (Ar)	39.944	1.44					A^{36} .37% 35 day 6 ± 2 barn A^{38} .063% 265 yr .8 ± .2 barn A^{40} 99.6% 109 min .53 ± .02 barn A^{41} (109 Min) >3.5 yr >0.06
Carbon Dioxide (CO_2)	44.010	O_2 = .094 .047 C = .047	C_2 CO_3 1.76 X 10^{-4}	2.0 X 10^{-6}		Organic composition of dust	C^{12} 98.98% 3.3 ± 0.2 m barn C^{13} 1.1% 5,570 yrs 1.0 ± 0.3 m barns C^{14} (5,570 yrs) 2.4 sec 1μ barn
Neon (Ne)	20.183	2.79X 10^{-3}					Ne^{20} 90.92% No activation Ne^{21} .26% No activation Ne^{22} 8.82 40 sec 36 ± 15 m barn
Helium (He)	4.003	8.12 X 10^{-4}					He^3 .00013% No activation He^4 100% No activation
Krypton (Kr)	83.7	1.55 X 10^{-4}					Kr^{78} .35% 24.4 hr 20 ± 05 barns Kr^{80} 2.27% Kr^{82} (11.56) Kr^{83} (11.55) No activation Kr^{84} 56.90% 4.4 hr 0.1 ± .03 barn 9.4 yr 60 ± 9.4 yr Kr^{85} No activation Kr^{86} 17.37% 77 min 60 ± 20 m barn Kr^{87} (77 min.) 2.8 hr < 600 barn

COMPOSITION (Continued)

Hydrogen (H_2)	2.0160	$7.75X10^{-5}$	H_2O 1.38 gm	$1.5 X10^{-1}$			H^1 ~ 100% No activation
Xenon (Xe)	131.3	$124X10^{-7}$					Xe^{124}, .096%, Xe^{125} .090%, Xe^{128} 1.29% No activation Xe^{129} 26.44%, Xe^{130} 4.08%, Xe^{131} 21.18% No activation Xe^{132} 26.89%, 5.3 day 0.2 ± 0.1 barn Xe^{134} 10.44% 9.13 hr 0.2 ± 0.1 barn Xe^{135} 9.13 hr No activation Xe^{136} 8.87% 3.9 min 0.15 ± .08
Ozone O_3	48.00	$155X10^{-8}$					O_3 as oxygen
Radon (Ra)							$<9.30 X 10^{-12}$ μ curies
Silicon (Si)					27%	$1.43X10^{-4}$	Si^{28} 92.27%, Si^{29} 4.69% No activation Si^{30} 3.05%, 2.62 hr. 110 ± 10 m barns
Aluminum AL					8%	$5.02 X10^{-5}$	AL^{27} 100% 2.27 min. 0.21 ± 0.04 barn
Iron (Fe)					5%	$1.51X10^{-5}$	Fe^{54} 5.84% 2.96 yr 2.2 ± 0.2 barn Fe^{56} 91.6% Fe^{51} 2.17% No activation Fe^{58} .31% 46 days 0.9 ± 0.2 barns
Calcium Ca			$CaSO_4$ $1.803X 10^{-3}$ $1.76 X 10^{-4}$	$1.25X10^{-5}$ $2.0X10^{-6}$	2.28%	$9.66X10^{-6}$	Ca^{40} 96.77%, Ca^{42} .64%, Ca^{43} .145% No activation Ca^{44} 2.06%, 152 days 0.63 ± .12 barns Ca^{46} .0033%, 4.8 days 0.25 ± 0.10 barns Ca^{48} .185%, 8.5 min. 1.1 ± 0.1 barns
Magnesium Mg			Mg cl_2 $5.44X 10^{-3}$ $MgSo_4$ $2.37 X 10^{-3}$ $MgBr_2$ $1.08X10^{-4}$	$1.14X10^{-4}$ $1.98 X 10^{-5}$ $5.90X10^{-7}$	2.28%	$1.61X10^{-5}$	Mg^{24} 78.60% Mg^{25} 10.11% No activation Mg^{26} 11.29%, 7.5 min 0.21 ± 0.04 m barns

COMPOSITION (Continued)

Potassium (K)	K_2SO_4 $1.233X10^{-3}$	$1.414X10^{-5}$	2.28%	$9.94X10^{-6}$	K^{39} 93.08% $1.3 X 10^9$ yr 3 ± 2 barns K^{40} .012% No activation K^{41} 6.91% 12.4 hr 1.0 ± .2 barn
Sodium (Na)	Nacl $3.90X10^{-2}$	$6.67X10^{-4}$	2.28%	$1.68X10^{-5}$	Na^{23} 100% 15.0 hr 0.56 ± .03 barns
Chlorine (Cl)	Nacl $3.90X10^{-2}$ $Mgcl_2$ $5.44X10^{-3}$	$6.67X10^{-4}$ $1.14X10^{-4}$			Cl^{35} 75.4% $3.08 X 10^5$ yrs. 30 ± 20 barns 87 day S^{35} 0.17 ± 0.04 barns Cl^{36} ($3.06 X 10^5$ yrs) 90 ± 30 barns Cl^{37} 24.6% 37.5 min 0.56 ± .12 barns
Sulphur (S)	$MgSO_4$ $2.37X10^{-3}$ $CeSO_4$ $1.8X10^{-3}$ $KsSO_4$ $1.233X10^{-3}$	$1.98 X 10^{-5}$ $1.25 X 10^{-5}$ $7.07X10^{-6}$			S^{32} 95.018% No activation S^{33} .750% 25.1 day, P^{32} 2.3 ± 1.0 m barn S^{34} 4.215% 87 day 0.26 ± 0.05 burns S^{36} .017% 5.0 min 0.14 ± .04 barns
Bromine (Br)	$MgBr_2$ $1.085X10^{-4}$	$1.180X10^{-6}$			Br^{79} 50.52%, 4.6 hr, 2.9 ± .05 barns 18 min 8.5 ± 1.4 barns Br^{81} 49.48 35.9 hr, 3.5 ± 0.5 barns
Silver (Ag)	$4 x 10^{-6}$ grains/kg				Ag 107 51.35 2.3 min 44 ± 9 barns Ag 109 270 days 2.8 ± .05 barns (48.65%) 24.2 sec 110 ± 20 barns
Gold (Au)	$4X10^{-6}$ grains/kg				Au 197, 100%, 2.7 days 96 ± 10 barns

Enclosure (2)

ACTIVATION

ISOTOPE		AIR $\mu C/SEC$	SALT WATER $\mu C/SEC$	DUST $\mu C/SEC$	TOTAL $\mu C/SEC$
N^{14}	99.36%				
N^{15}	.37%	49			49
O^{16}	99.59%				
O^{17}	.037%	1.157×10^{-6}	1.37×10^{-9}	8.75×10^{-11}	$4.82- \times 10^{-5}$
O^{18}	.204%	$.162 \times 10^{2}$	1.92×10^{-3}	1.24×10^{-4}	$.162 \times 10^{2}$
A^{36}	.37%	1.8×10^{-2}			1.8×10^{-2}
A^{38}	.063%	1.61×10^{-6}			1.61×10^{-6}
A^{40}	99.6%	1.98×10^{3}			1.98×10^{3}
A^{41}	(109) min.	1.05×10^{-15}			1.05×10^{-15}
C^{12}	(98.98%)			Estimate that no organic material in dust is probably erroneous	
C^{13}	1.1%	2.02×10^{-11}	2.8×10^{-27}		2.02×10^{-11}
C^{14}	(5,570 yrs.)	10^{-16}	0		10^{-16}
Ne^{20}	90.92%				
Ne^{21}	.26%				
Ne^{22}	8.82%	3.7×10^{-2}			3.7×10^{-2}
He^{3}	.00013%				
He^{4}	100%				
Kr^{28}	.35%	1.49×10^{-4}			1.49×10^{-4}
Kr^{80}	Kr^{83}				
Kr^{84}	56.90%	94 4.4 hr. 1.67×10^{-13} 9.4 yr.			94 4.4 hr. 1.67×10^{-13} 9.4 yr.
Kr^{85}					
Kr^{86}	17.37%	3.55×10^{-2}			3.55×10^{-2}
Kr^{87}	(77 min.)	12×10^{-3}			12×10^{-3}
H^{1}	100%				

ACTIVA..ON (Continued)

ISOTOPE		AIR μC/SEC	SALT WATER μC/SEC	DUST μC/SEC	TOTAL μC/SEC
Xe^{132}	(26.89)	6.76×10^{-5}			6.76×10^{-5}
Xe^{134}	(10.44%)	8.72×10^{-2}			8.72×10^{-2}
Xe^{136}	8.87%	.119			.119
Rn		9.30×10^{-12}			9.30×10^{-2}
Si^{30}	3.05%			.0516	.0516
Al^{27}	100%			1.31	1.31
Fe^{54}	5.84%			3.52×10^{-7}	3.52×10^{-7}
Fe^{58}	.31%			4.3×10^{-6}	4.3×10^{-6}
Ca^{44}	2.06%		2.38×10^{-7}	1.57×10^{-7}	3.95×10^{-7}
Ca^{46}	3.3×10^{-3}%		4.88×10^{-8}	3.26×10^{-9}	5.20×10^{-8}
Ca^{48}	.185%		9.77×10^{-4}	6.52×10^{-4}	16.2×10^{-4}
Mg^{26}	11.29%		2.07×10^{-2}	2.64×10^{-3}	2.334×10^{-2}
K^{39}	93.08%		1.21×10^{-15}	8.56×10^{-16}	2.06×10^{-15}
K^{41}	6.91%		3.72×10^{-4}	2.62×10^{-4}	6.34×10^{-5}
Na^{23}	100%		11.7×10^{-2}		11.7×10^{-2}
Cl^{35}	75.4%		2.78×10^{-8}		2.78×10^{-8}
			3.25×10^{-4}	(S^{35})	3.25×10^{-4}
Cl^{36}	(3.08×10^{5} yrs)				
Cl^{37}	24.6%		.476		.476
S^{33}	.750%		1.61×10^{-8}		1.6×10^{-8}
S^{34}	4.215%		2.3×10^{-5}		2.3×10^{-5}
S^{36}	.017%		5.23×10^{-6}		5.23×10^{-6}
Br^{79}	50.52		1.75×10^{-3} (4.6 hr)		1.75×10^{-3} (4.6 hr.)
			7.8×10^{-1} (18 min.)		7.8×10^{-1} (18 min.)
Br^{81}	49.48		2.70×10^{-5}		2.70×10^{-5}